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APPLICATION FOR LETTERS PATENT:

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Spindle-Motor Driven Pump System

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INVENTORS

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Spindle-Motor Driven Pump System

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] None

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] This invention was made with Government support under contract #N68335-00-D-0451 awarded by the Defense Microelectronics Activity. The Government has certain rights in this invention.

BACKGROUND

Field of the Invention

[0003] The present invention relates to a pump driven by a hard drive type brushless direct current (DC) spindle-motor, suitable for use with liquid cooling systems.

Description of the Related Art

[0004] Liquid cooling is well known in the art of cooling electronics. As air cooling heat sinks continue to be pushed to new performance levels, so has their cost, complexity, and weight. Liquid cooling systems provide advantages over air cooling in terms of heat removal rates, component reliability and package size.

[0005] Liquid cooling removes energy from heat generating components through sensible or latent heat gains of a cooling fluid. The cooling fluid is continuously pressurized by a pump and may be delivered to a thermal management block. The cooling fluid may also be dispensed within a globally cooled enclosure. After the cooling fluid is heated by an electronic component to be cooled, the surplus energy of the fluid is removed by a heat exchanger, or condenser. The cooled fluid exits the heat exchanger and is delivered back to the pump, thus forming a closed loop system.

[0006] There are many different liquid cooling systems. Although each type of liquid cooling system may have a unique thermal management block, the closed loop cooling systems are likely to share the common need of pressurizing a supply of liquid coolant. For example: U.S. Pat. No. 6,234,240 discloses a single phase closed loop cooling system; a microchannel liquid cooling system is described by U.S. Pat. No. 4,450,472; an exemplary liquid cooling system is described by U.S. Pat. No. 5,220,804 for a two-phase spray cooling system utilizing a thermal management block; and a globally liquid cooled enclosure is

described by U.S. Pat. No. 6,139,361. As described by the '804 patent, spray cooling is capable of absorbing high heat fluxes. Nozzles, or preferably atomizers, break up a supply of liquid coolant into numerous droplets that impinge the surface to be cooled. The size, velocity and resulting momentum of the droplets contributes to the ability of the thermal management unit to absorb heat. These characteristics, and thus the overall performance of the thermal management system are impacted by the performance of the pump. To achieve reliable system performance, it is important that the pump deliver accurate performance over a long life cycle. It is known that pumps driven by DC motors can be used with liquid cooling pumps. U.S. Pat. No. 6,447,270 describes a large scale DC brushless motor used for spray cooling. U.S. Pat. No. 6,193,760 describes a highly specialized DC brushless motor system wherein a rotor creates both the pumping and motor force. U.S. Pat. No. 5,731,954 describes a brushless motor mounted within a reservoir casing.

[0007] Desirable features of any liquid cooling system are low cost, high reliability and high performance. Optimization of the pump impacts all three features. Thus, there is a need for a pump that contains a motor with a proven history of high reliability. Thus, there is a need for a pump that contains a motor that can be produced for a low cost. Thus, there is a need for a pump that is compact in size. Furthermore, there is a need for a pump that is efficient in creating its output. Also furthermore, there is a need for a pump that is capable of producing significant pressures.

BRIEF SUMMARY OF THE INVENTION

[0008] In order to solve the problems of the prior art, and to provide a highly reliable liquid pump that can produce significant pressures in a compact space for a low cost and with high reliability, a spindle-motor driven pump system has been developed.

[0009] The present invention is a compact pump that is powered by a brushless DC spindle-motor, as used in disk drives and CD-ROM drives. A hard drive type spindle-motor is a brushless DC motor that is highly balanced, very reliable, available at low cost, and is capable of significant rotational speeds. According to the present invention, a spindle-motor is mounted to a pump housing and to an impeller within the housing. The spindle-motor rotates the impeller causing movement of a fluid. Preferably for spray cooling, the pump is a turbine pump.

[0010] These and other features, aspects, and advantages of the present invention will become better understood with regard to the following description, and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] In the course of the detailed description to follow, reference will be made to the attached drawings. These drawings show different aspects of the present invention and, where appropriate, reference numerals illustrating like structures, components, and/or elements in different figures are labeled similarly. It is understood that various combinations of the structures, components, and/or elements other than those specifically shown are contemplated and within the scope of the present invention:

[0012] Figure **1** is a perspective view of a turbine pump according to the present invention;

[0013] Figure **2** is a side section view of the pump of Figure **1** cut through its midplane;

[0014] Figure **3** is a perspective view of the assembly of an impeller to a spindle motor, according to the present invention;

[0015] Figure **4** is a partial perspective view of a turbine impeller including a plurality of impeller vanes, also shown is a fluid pressure equalization hole;

[0016] Figure **5** is a perspective view of a pump body having a fluid channel (shown with bolded lines for clarity);

[0017] Figure **6** is a perspective view of a pump base having a fluid channel (shown with bolded lines for clarity), wherein the body fluid channel of Figure **5** and the base fluid channel of Figure **6** form a fluid cavity;

[0018] Figure **7** is an exploded perspective view of the pump of Figure **1**;

[0019] Figure **8** is a top perspective view of an alternative embodiment centrifugal pump;

[0020] Figure **9** is a bottom perspective view of the alternative embodiment shown in Figure **8** and with the bottom cover removed for visibility of the centrifugal impeller and vanes; and

[0021] Figure **10** is a plot showing the flow rate versus pressure performance of the pump of Figure **1**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0022] Many of the fastening, connection, manufacturing and other means and components utilized in this invention are widely known and used in the field of the invention are described, and their exact nature or type is not necessary for a person of ordinary skill in the art or science to understand the invention; therefore they will not be discussed in detail.

[0023] The terms "a", "an", and "the" as used in the claims herein are used in conformance with long-standing claim drafting practice and not in a limiting way. Unless specifically set forth herein, the terms "a", "an", and "the" are not limited to one of such elements, but instead mean "at least one".

[0024] Applicant hereby incorporates by reference U.S. Patent No. 5,220,804 for a high heat flux evaporative cooling system. Although spray cooling is herein described as the preferred method of liquid cooling, the present invention is not limited to such a thermal management system. The discussion of spray cooling is only provided as a preferred use of the present invention.

[0025] Now referring to Figure **1**, a spindle-motor driven pump system **20** is shown. Although not limited to any particular range, pump system **20** shown and described herein is designed to deliver fluid pressures and flow rates in the range needed to provide liquid cooling of electronic components. Typically, these values are less than 40 pounds per square inch (psi) of pressure and around 500 milliliters per minute (ml/min) of flow per component to be cooled. These ranges

of performances, and others, may be attained through the many possible embodiments of the present invention.

[0026] Pump system **20** is mainly comprised of a spindle-motor **30**, a cap **50**, a body **60**, a base **70**, and an impeller **40**. Overall dimensions of the preferred embodiment of Figure **1** are roughly 2 inches wide, 2 inches long, and 1 inch tall. Each of the components of system **20** may be made from any commonly known material or process, including aluminum, die cast metals, molded plastic, and the such. If plastic is to be used in contact with the cooling fluid Fluorinert (a trademark of 3M) it is preferred that polyethylene-terephthalate (PET) be used.

[0027] Spindle-motor **30** is a commercially available DC brushless spindle motor as used with computer hard drives. Hard drive spindle-motors are typically available in the range of less than one-fifth horsepower. U.S. Pat. No. 5,006,943; U.S. Pat. No. 5,402,023; U.S. Pat. No. 6,543,781; and U.S. Pat. No. 5,942,820 all describe the construction and function of hard drive type spindle-motors applicable to the present invention, and are herein incorporated by reference to this application. Generally, DC brushless spindle-motor **30** is comprised of a stationary shaft **31** having high precision magnetic bearings which rotatably support an outer hub **32**. One or both of ends of hub **32** may contain a magnetic seal which isolates the insides of spindle-motor **30** from the outside atmosphere. Typically, the magnetic seals will include a magnetic fluid for increased sealablity. Rare-earth magnets in combination with a controller and a stator assembly

provide the means of rotating hub **32** around the stationary shaft according to well know electric motor principles. The rare-earth magnets contained within spindle-motor **30**, typically constructed from neodymium-iron-boron or samarium-cobalt, provide a higher magnetic flux than alnico or ferrite permanent magnets common to standard DC brushless motors. The rare-earth magnets provide the means of faster motor start ups, faster rotations, more reliable performance and more compact systems, in comparison to standard DC brushless motors. With spindle-motors, such as spindle-motor **30** shown herein, hub **32** is provided in a fashion that allows it to be mounted to the disk like "platters" of a hard drive, very similar to the mounting of impeller **40** of the present invention. Because the exact configuration and construction of DC brushless spindle-motor **30** is not central to the present invention, hereinafter spindle-motor **30** will be described in general terms as warranted for a person skilled in the art to understand and appreciate the present invention. The attached drawings show only the features of spindle-motor **30** necessary to practice the invention.

[0028] Significant efforts have been expended in the development and progress of rare-earth spindle motors which make them ideal for liquid cooling pumps. First, because of the mass production rates associated with hard drives, spindle-motor **30** is available at low costs. Second, spindle-motor **30** is highly balanced and does not contain any significant wear parts resulting in very reliable performance. In fact, spindle-motor **30** is commonly available with average mean times between failures (MTBF's) in the range of 800,000 hours. Third, spindle-

motor **30** is capable of fast rotational speeds. Rare-earth magnets within spindle-motor **30** provide the means of allowing hub **32** to achieve speeds ranging from 3600 rotations per minute, typical of laptops hard drives, to over 15,000 rpm's, as typical of high performance SCSI hard drives motors. Large rpm's allow the size of pump system **20** to be minimized. Fourth, the output power of hard drive spindle-motors coincide with the cooling needs of many electronic components. Fifth, because hard-drive motors are compact and well balanced they are efficient in creating their output. Efficiency is a desirable feature of liquid cooling systems.

[0029] Referring back to Figure **1**, body **60** is sandwiched between cap **50** and base **70**. A plurality of screws **23** hold the assembly together by passing through mounting holes of cap **50,** and screw holes **63** of body **60**, and into a plurality of screw threads **72** of base **70** (the assembly can be best seen by Figure **7**). The top surface of body **60** has a cap seal groove **65** and the bottom surface of body **60** has a base seal grove **66**. Seal grooves **65** and **66** each work with an o-ring **22** for sealing a closed cavity created between cap **50**, body **60** and base **70**. O-ring **22** has a cross-sectional diameter of 0.0875 inches, an outside diameter of 2 inches, and is made from Viton (a trademark of Dupont). Grooves **65** and **66** are 0.095 inches wide, 0.051 inches tall and start 0.921 inches from the center axis of base **70**. Although o-ring **22** of the present invention is made from Viton (a trademark of Dupont), as to be compatible with

the cooling fluid Fluorinert (a trademark of 3M), o-ring **22** can be made from other materials compatible with the chosen fluid to be pumped.

[0030] Within the cavity created by cap **50**, body **60** and base **70**, is spindle-motor **30** and an impeller **40**. Spindle-motor **30** may be secured to the assembly in multiple ways depending on the chosen motor type and manufacturer. A first securing method utilizes the input connector **33**, which supplies electrical energy to the stator assembly. Input connector **33** may contain exterior threads that engage with interior threads of a ring **36**. Another method of securing spindle-motor **30** to pump assembly **20** is through the use of a mounting thread **34** contained within stationary spindle **31** (Figure **3**). A motor screw (not shown) is placed through a mounting hole **51** of cap **50**, and into mounting thread **34**. Both securing methods fix stationary shaft **31** and allow for the rotation of hub **32**. Either, or both, securing methods are acceptable and because they are driven by spindle-motor manufacturers, other methods may be used within the spirit of the present invention.

[0031] Best shown by Figure **3**, attached to hub **32** is impeller **40** which is preferably a turbine type. Impeller **40** according the preferred embodiment is 0.07 inches thick, has an inner diameter of 0.975 inches, and an outside diameter of 1.554 inches. Other designs and dimensions are possible following well known pump design guides. Impeller **40** coaxially fastens to the exterior surfaces of hub **30** by the engagement of posts **42** with recesses **35**, located in hub **32**. The combination of posts **43** with recesses **35** constrain impeller **40**

rotationally, but allow it to float axially. The ability to mount impeller **40** directly to the exterior of hub **32** allows pump system **20** to take up less space than prior art DC brushless motor systems. Again, these interconnecting features may change depending upon the commercial source of spindle-motor **30** and the mounting features therein provided. With the preferred embodiment, posts **43** are 0.80 inches tall by 0.12 inches wide by 0.05 inches deep, and engage with recesses **35** that are 0.14 inches wide by 0.076 inches deep.

[0032] The rotational constraint of impeller **40** to hub **32** of spindle-motor **30** provides the means for moving impeller **40** with angular velocities over 3600 rpm's. As shown in Figure **4**, both sides of impeller **40** contain a radial array of turbine vanes **41**. Vanes **41** are offset from the top side to the bottom side for a more consistent loading of spindle-motor **30**. According to the preferred embodiment, each of vanes **41** are 0.0625 inches wide, by 0.625 inches deep and spherical in construction. Impeller **40** rotates through a fluid cavity created by a body fluid channel **64** and a base fluid channel **71**, highlighted by Figure **5** and Figure **6**. In the case of the preferred embodiment, the fluid cavity has dimensions of 0.08 inches wide and protrudes 0.025 inches above vanes **41** of impeller **40**. There is a 0.0005 to 0.004 inch clearance between impeller **40** and body **60** and base **70.** This clearance allows fluid to fill the gap and lubricate the motion of impeller **40**. A plurality of fluid bypass holes **42** allow for fluid pressures to equalize between the two sides of impeller **40.** Furthermore, the

interaction between posts **43** and recesses **35** allow impeller **40** to float within the fluid cavity, resulting in low friction and high efficiencies.

[0033] Body **60** has a first fluid fitting orifice **61** and a second fluid fitting orifice **62** each connected to the fluid cavity. Depending upon the rotational direction of spindle-motor **30**, and the resulting rotational direction of impeller **40**, the plurality of vanes **41** draw fluid in through first fluid fitting orifice **61** and push the fluid out second fluid fitting orifice **62**, or vice-versa. Connected to both first orifice **61** and second orifice **62** are a fluid fitting **24**. Although fluid fitting **24** is shown as a press-on barbed fitting, a number of widely known fittings may be employed including "quick-disconnect" fittings.

[0034] Pump performance characteristics, such as pressure and flow rates, are largely driven by the design of impeller **40**. The diameter and speed of impeller **40** determine the tangential velocity of vanes **41**. The tangential velocity of vanes **41** contribute to determining the resulting pressure and flow rate of pump system **20**. For a given application that requires a particular pump performance and a resulting tangential speed of vanes **41**, the large rpm's of spindle-motor **30**, created by its at least one rare-earth magnet, provides the means of minimizing the diameter of impeller **40** and the overall package size of system **20**. Figure **10** provides test data correlating flow rate versus pressure for the compact preferred embodiment described herein.

[0035] Additional benefits come from using spindle-motor **30** within pump system **20**. One such benefit is that the dielectric fluid commonly used as a liquid

coolant further improves the performance of spindle-motor **30** in comparison to its use with hard drives. As previously described, spindle-motor **30** may contain a magnetic fluid for improved sealiblity. Although this feature is needed for disk drive applications, as to keep contaminants away from the sensitive magnetic memory disks, this feature is not needed for liquid cooling. In fact, with the addition of the dielectric fluid into the present invention, the less viscous cooling fluid displaces the magnetic fluid and results in less friction acting against spindle-motor **30**. Pump system **20**, according to the present invention, is figured to be 8% efficient. In addition, it has been shown that the cooling fluid provides cooling of spindle-motor **30** which may increase its life and reliability.

[0036] The use of pump system **20** is typical of pumping systems. Preferably a common "sensorless" hard drive motor control system delivers power to a series of input pins of connector **33** which correspond to a plurality of groups of coils within spindle-motor **30**. Depending upon the size of motor **30** and the desired speed, input powers can typically be between 5 and 12 volts, and with a current of one-half to 3 amperes. The input power is transferred into a magnetic field which causes hub **32** to rotate according to well known electric motor practice. The rotation of hub **32** causes impeller **40** to rotate which results in movement of vanes **41**. Vanes **41** draw a supply of low pressure fluid and transform it into a higher pressure supply of fluid. The flow of fluid is directed by connecting tubes to fittings **24**.

[0037] Other embodiments of the present invention are possible. One such embodiment is shown in Figure **8** and Figure **9** wherein a centrifugal pump system **76** is shown. This embodiment employs and gains the advantages of spindle-motor **30**, but rather than using turbine impeller **40**, this embodiment utilizes a centrifugal impeller **77** that contains a series of centrifugal vanes **78**. Fluid enters through an inlet directed at the central axis of centrifugal impeller **77** (not shown) and is pressurized through the radial forces created by centrifugal vanes **78,** according to well known centrifugal pump operation. The pressurized fluid is dispensed through exit **79**. This centrifugal embodiment version of the present invention produces higher flow rates, but at a reduced pressure, than the turbine embodiment. Although the turbine version is preferred for use with spray cooling, the centrifugal version may be desirable in other pumping applications. Positive displacement gear pumps may also be desirable in certain applications. The present invention is not limited to any one known pumping method. With any pumping method, and according to the present invention, it is highly desirable to design the pumping method to be integrated with the well adopted, highly reliable, high RPM, and low cost spindle-motor **30.**

[0038] While the low spindle motor driven pump herein described constitute preferred embodiments of the invention, it is to be understood that the invention is not limited to these precise form of assemblies, and that changes may be made therein with out departing from the scope and spirit of the invention.

ELEMENTS BY REFERENCE NUMBER

#	NAME	#	NAME
20	**Pump System**	50	Cap
21		51	Mounting Hole
22	O-ring	52	
23	Screw	53	
24	Fluid Fitting	54	
25		55	
26		56	
27		57	
28		58	
29		59	
30	**Spindle Motor**	60	**Body**
31	Stationary Spindle	61	First Fluid Fitting Orifice
32	Hub	62	Second Fluid Fitting Orifice
33	Connector	63	Screw Holes
34	Mounting Thread	64	Body Fluid Channel
35	Recesses	65	Cap Seal Groove
36	Ring	66	Base Seal Groove
37		67	
38		68	
39		69	
40	**Impeller**	70	**Base**
41	Turbine Vanes	71	Base Fluid Channel
42	Fluid Bypass Holes	72	Screw Threads
43	Impeller Posts	73	
44		74	
45		75	
46		76	**Centrifugal Pump System**
47		77	Centrifugal Impeller
48		78	Centrifugal Vanes
49		79	Exit